When will we detect changes in cloud height with spaceborne cloud radar?

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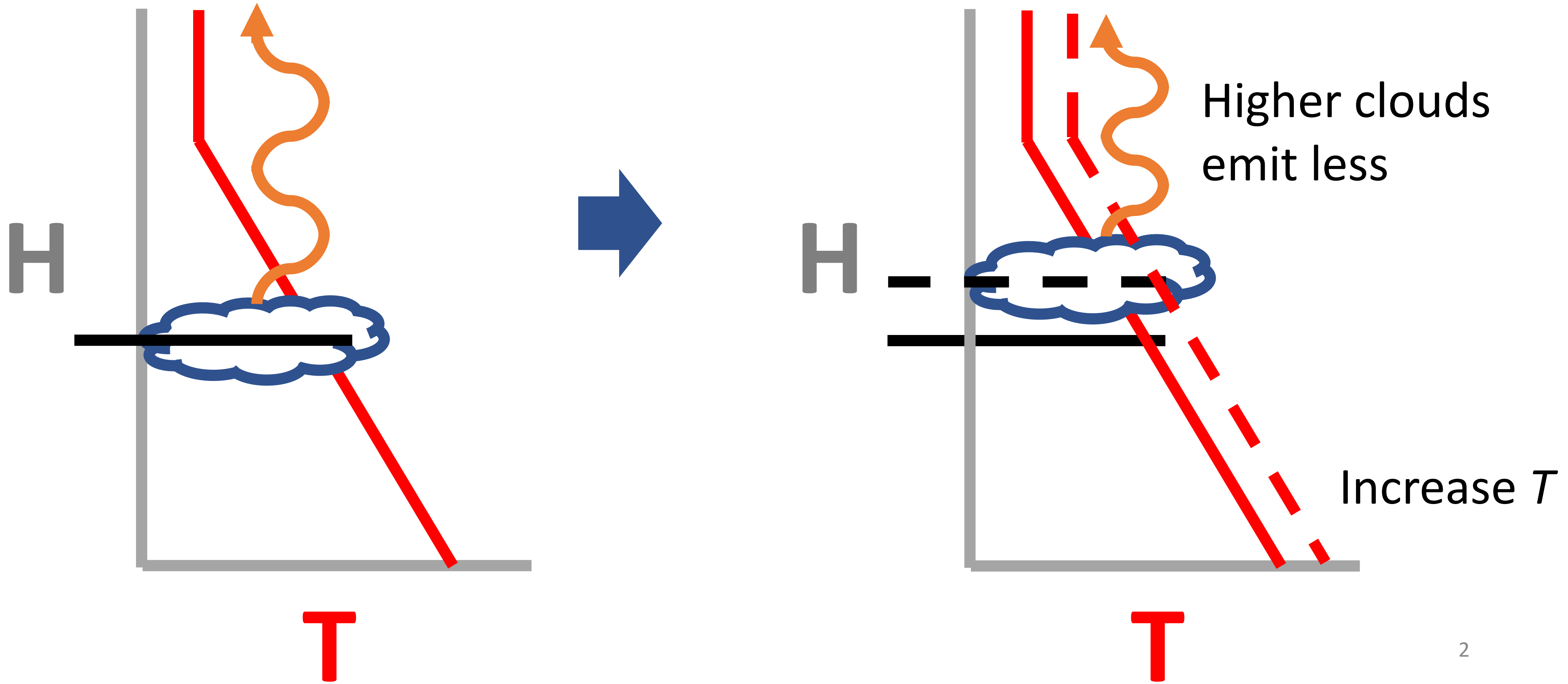
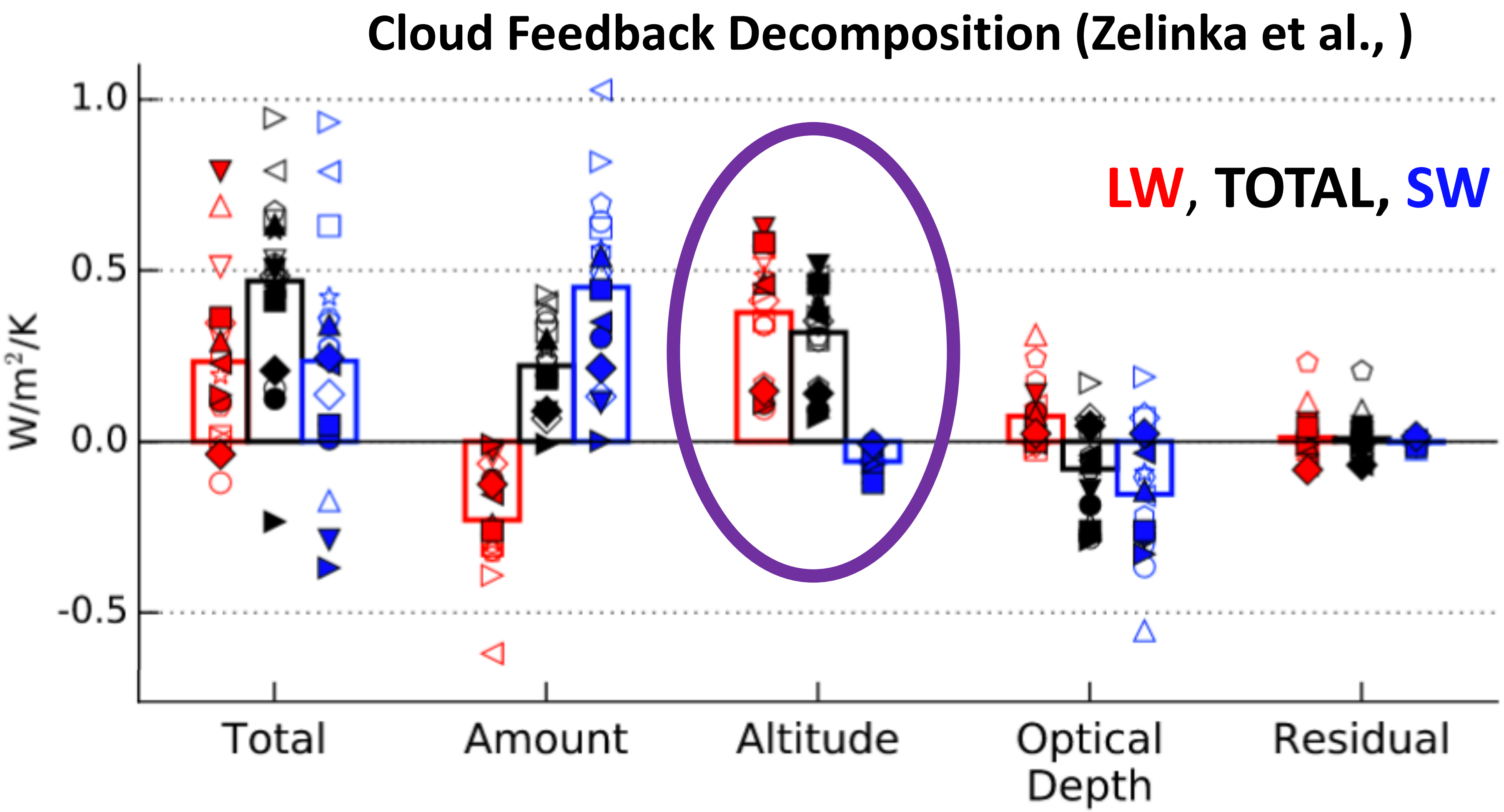
Why Altitude of High Clouds?

- As the climate warms, models robustly predict they rise and reinforce warming.

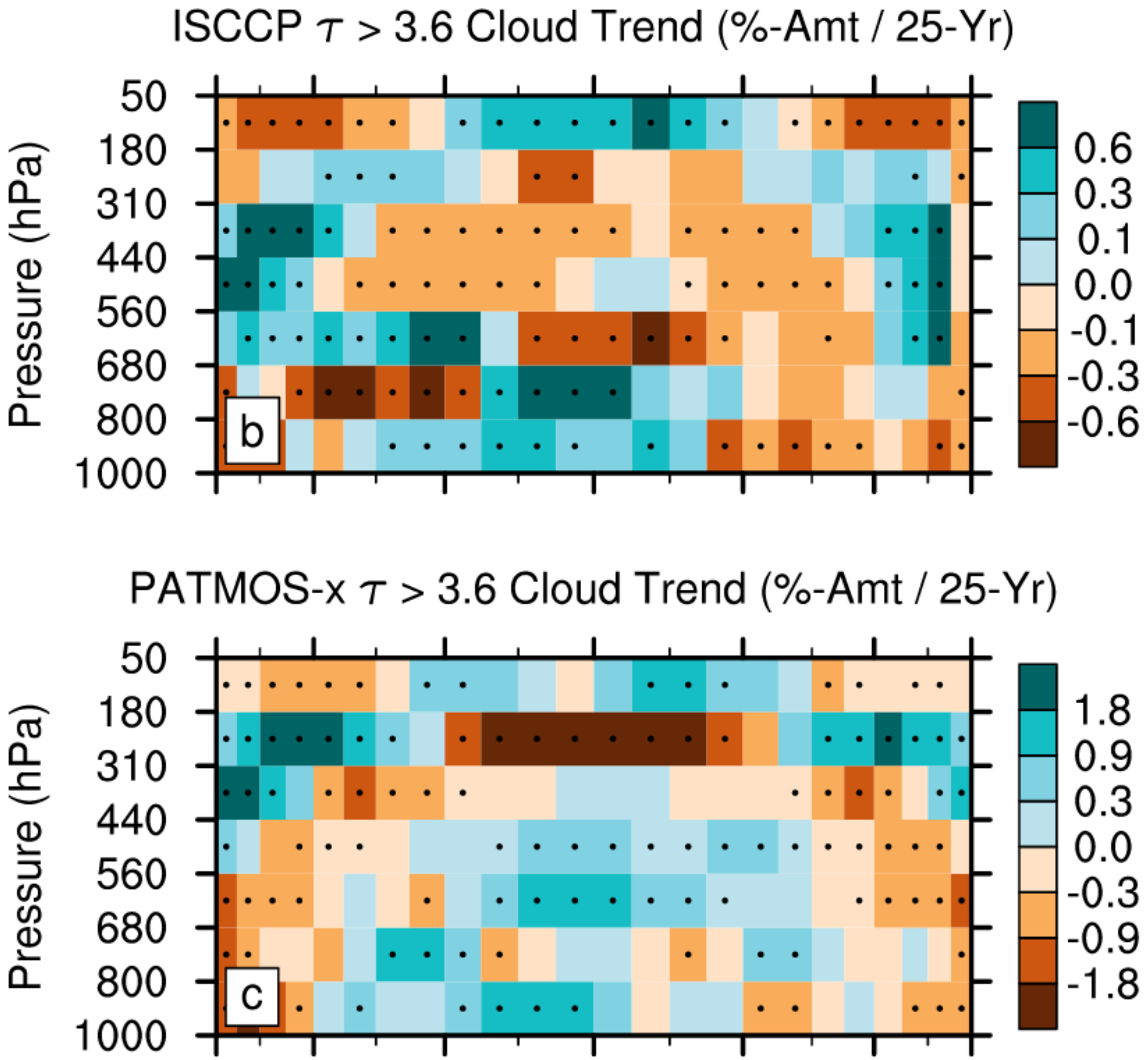


Why Altitude of High Clouds?

- The magnitude of this upward shift affects the longwave cloud feedback.



When will we see trends in cloud heights?



- Measurements of IR Tb from weather satellites suggest that detectable trends in cloud heights are already observable.
- However these observations are indirect and were not designed for monitoring climate.

[*Norris et al., 2015*]

When will we see trends in cloud heights?

AGU PUBLICATIONS

Geophysical Research Letters

RESEARCH LETTER
10.1002/2014GL061792

Where and when will we observe cloud changes due to climate warming?

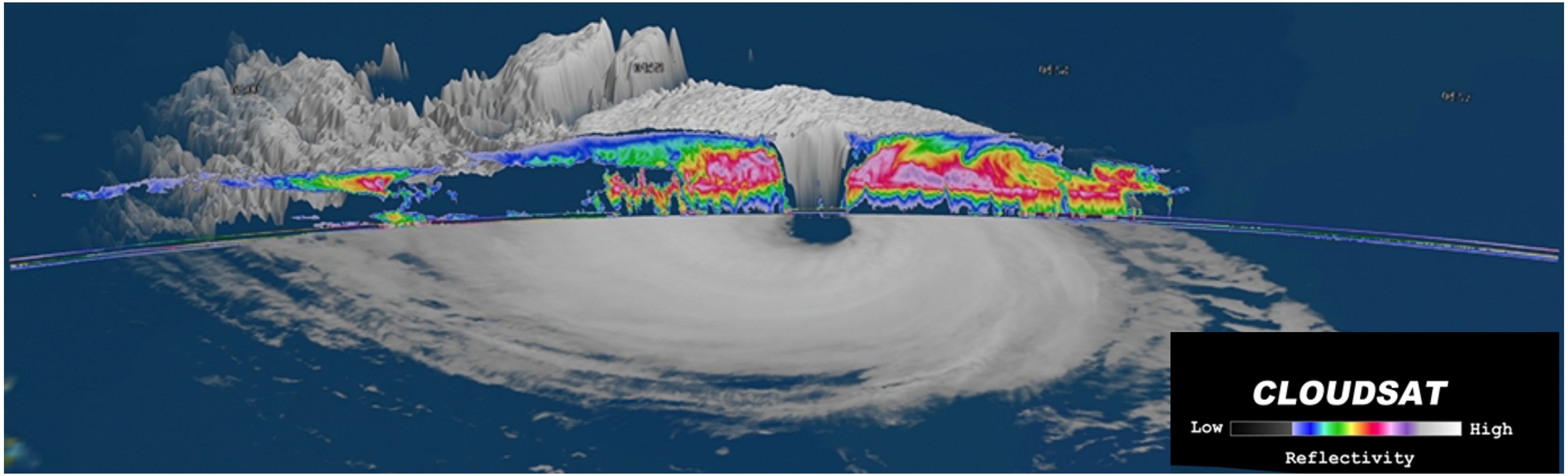
H. Chepfer[1], V. Noel[2], D. Winker[3], and M. Chiriaco[4]

Key Points:
- Cloud vertical distribution is sensitive

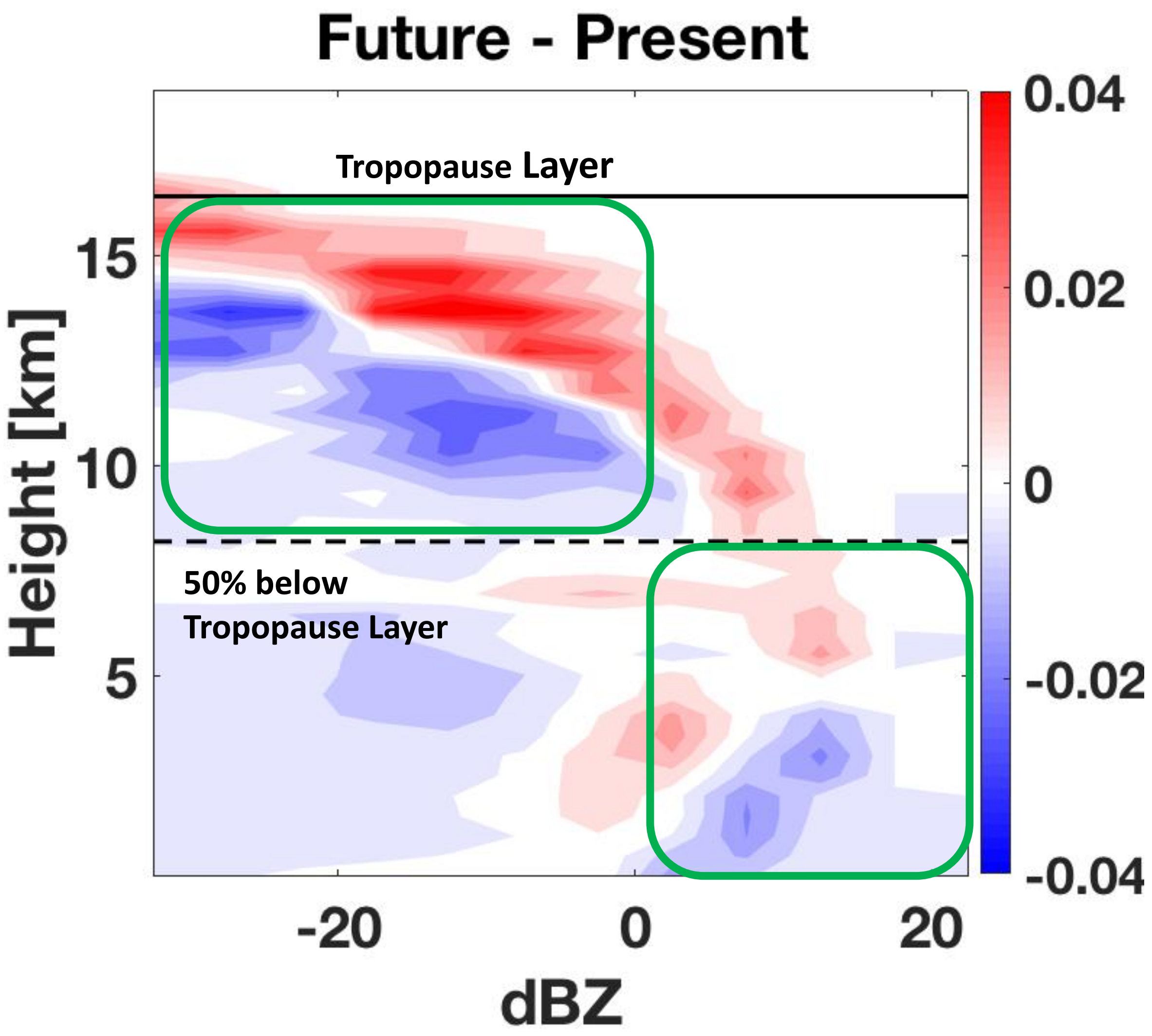
- A spaceborne **lidar** will likely require a data record of several decades to detect upward shifts in cloud heights.
- Inspired by this work, we determine when a spaceborne cloud **radar** may detect the upward shifts in cloud heights.

Data

- 90-year of the Community Earth System Model version 1 (**CESM1**) forced by the Representative Concentration Pathway (**RCP**) **8.5** emission scenario.
- The model is coupled to the CFMIP Observation Simulator Package (**COSP**).
- COSP outputs monthly gridded Contoured Frequency by Altitude Diagrams (**CFADs**) of radar reflectivity at **W-band** with 480 m resolution to emulate the **CloudSat** observations.

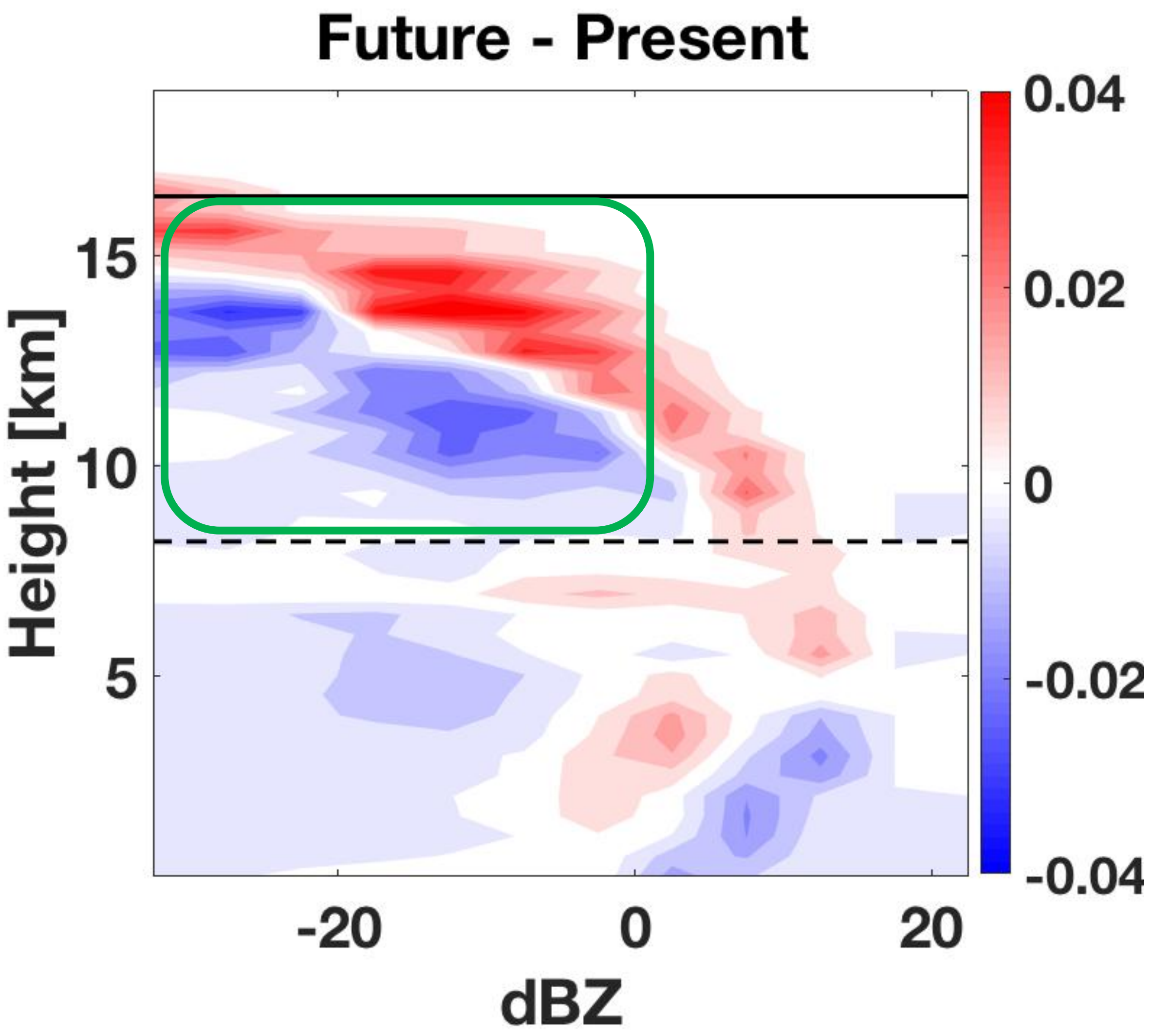


Data: CFAD



- RCP8.5 change 2005—2016 to 2086—2095 for the latitudes between 0-10°N
- The clear upward shift in the clouds as measured at all reflectivities less than 0 dBZ.
- Reflectivities greater than 0 dBZ begin to show the signatures of precipitation instead of cloud.

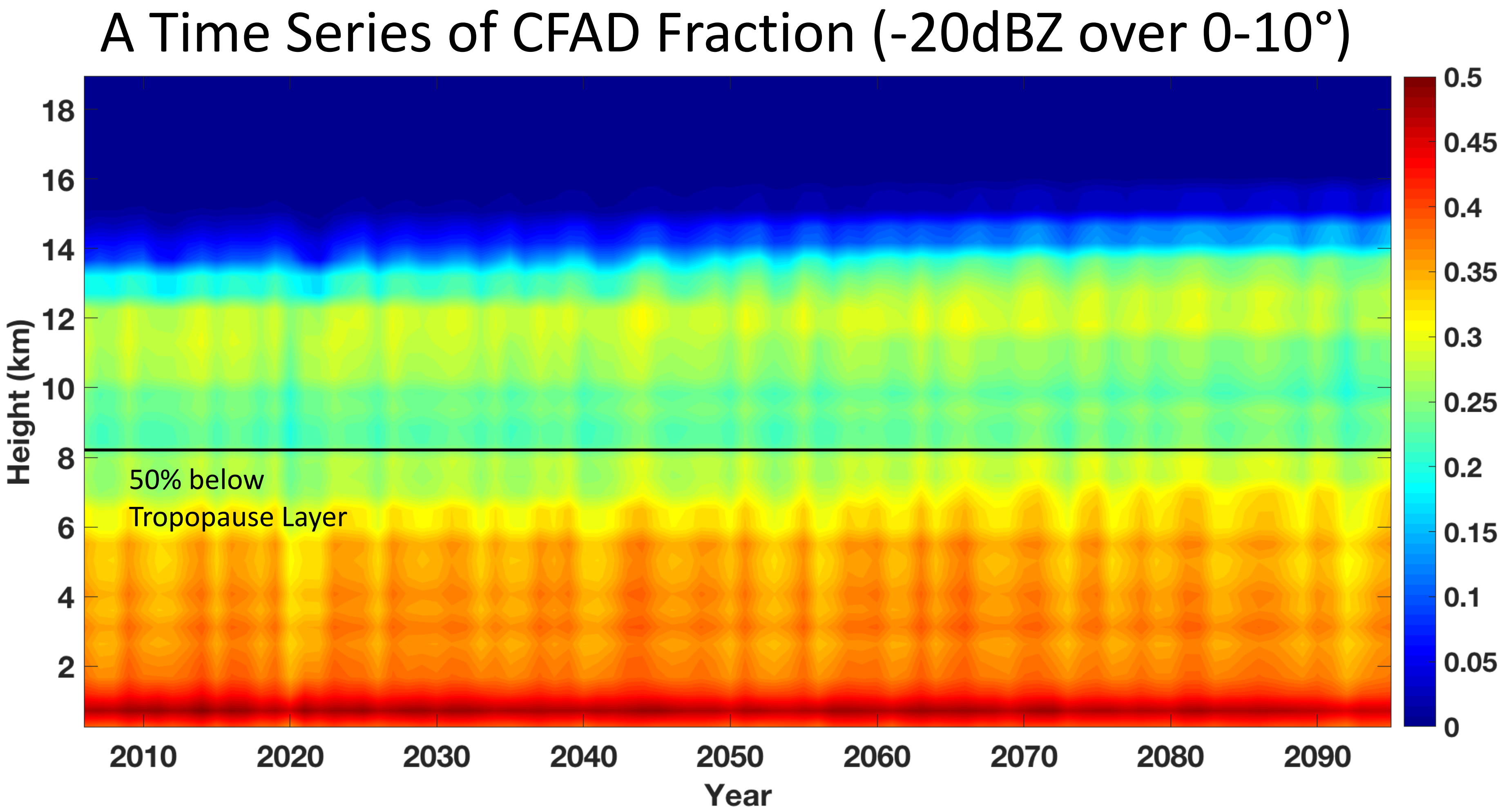
Method: How do we quantify this shift?



How do we work out detection:

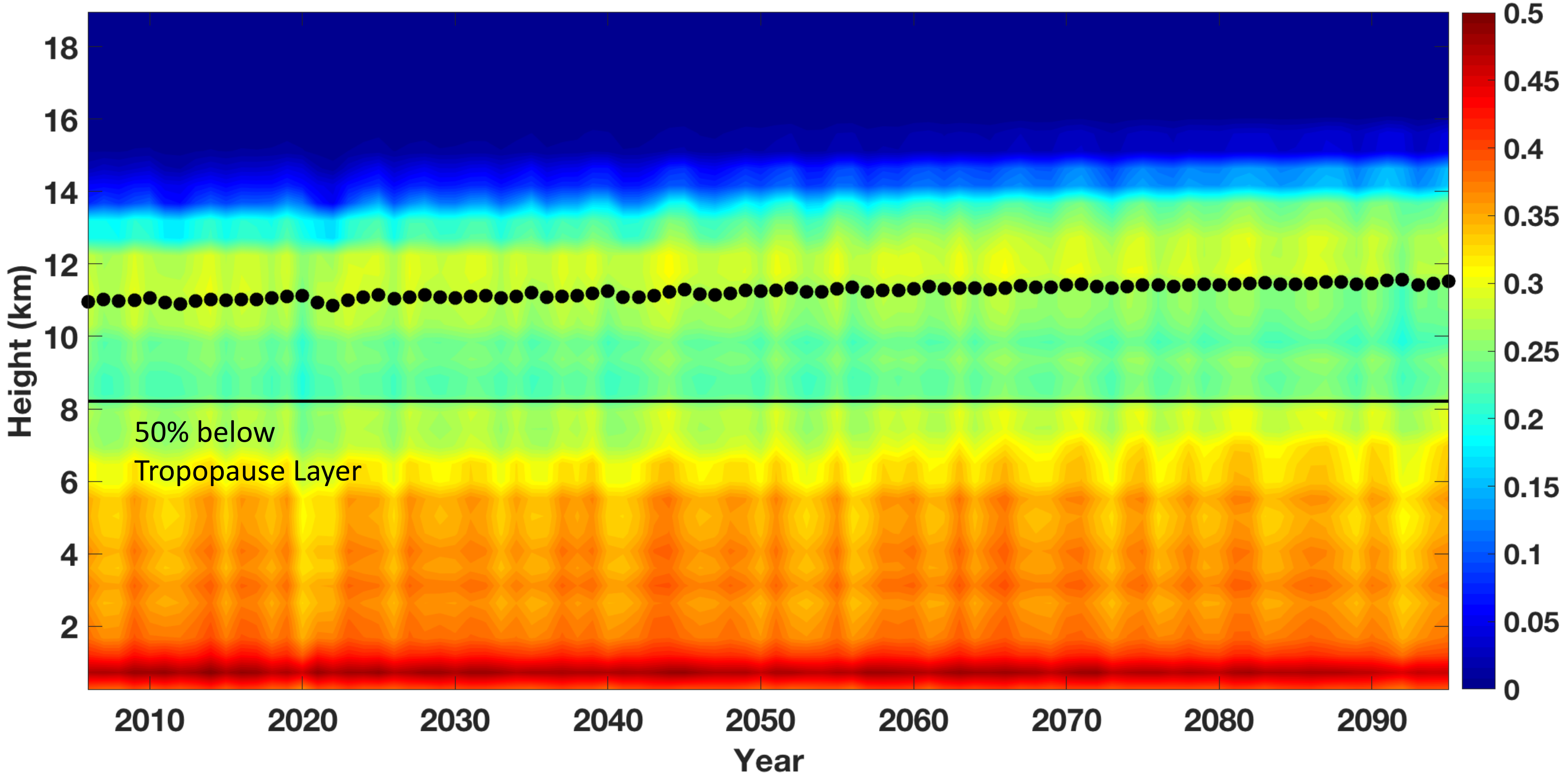
- Year?
- Location?
- dBZ requirement?
- Instrument calibration?

Method: How do we quantify this shift?



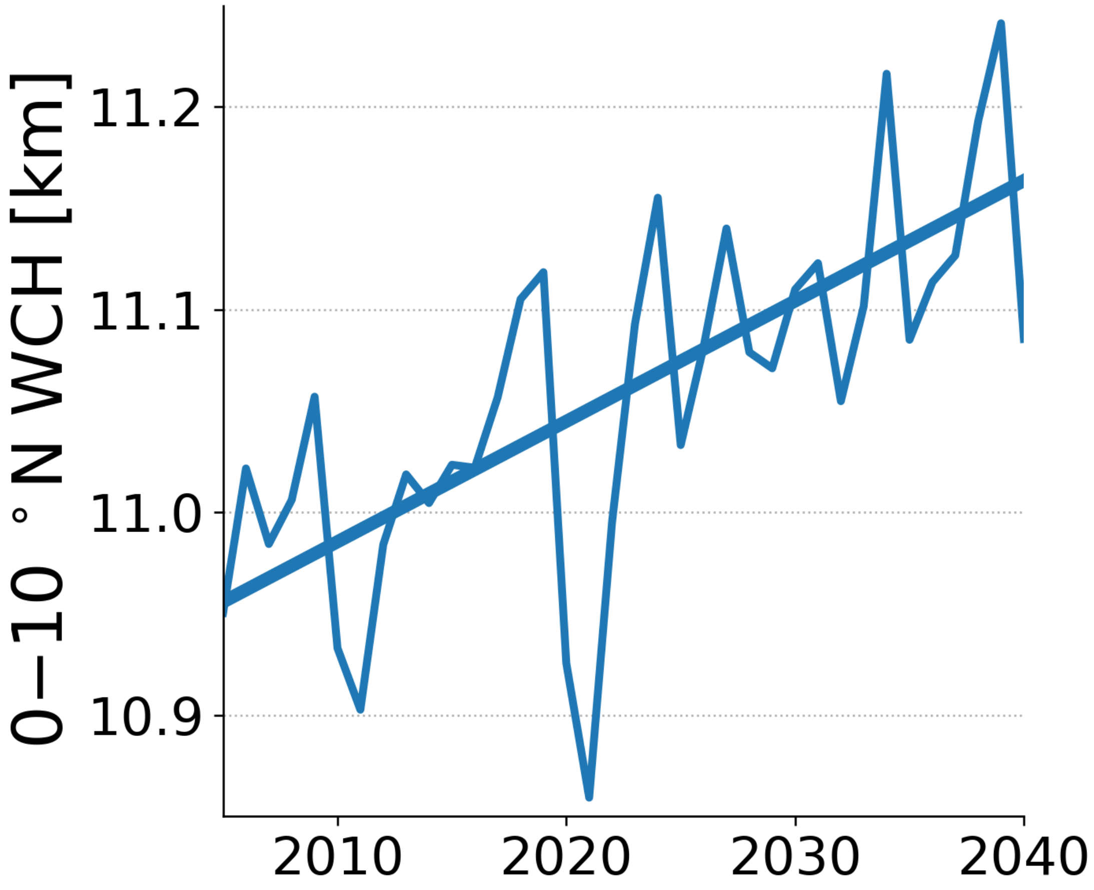
Method: Weighted Cloud Height (WCH)

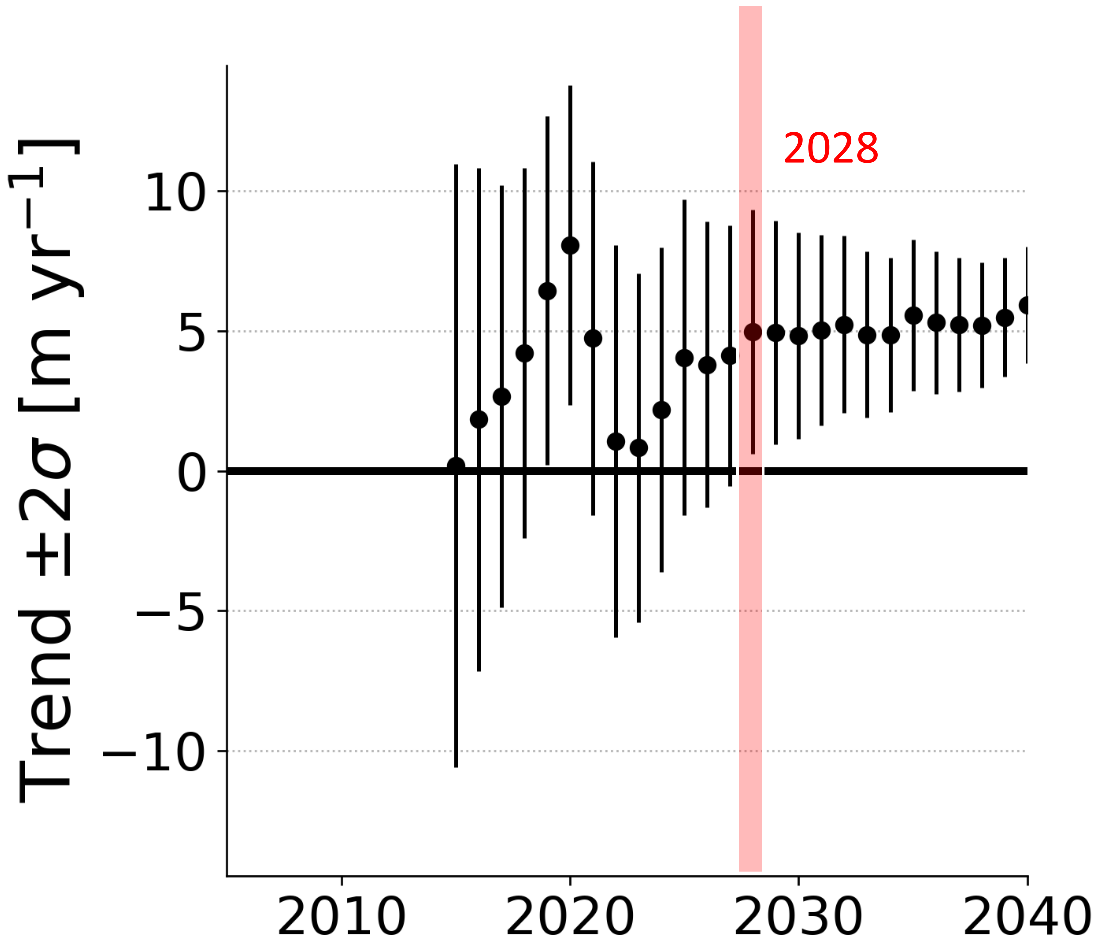
$$WCH(\mathrm{dBZ}) = \frac{\sum_{i,TL50}^{i,TOA} H_i \times CFAD(H_i, dBZ)}{\sum_{i,TL50}^{i,TOA} CFAD(H_i, dBZ)}$$



Method: How do we quantify this shift?

- Our detection year is first year that's significant with all years after being significant

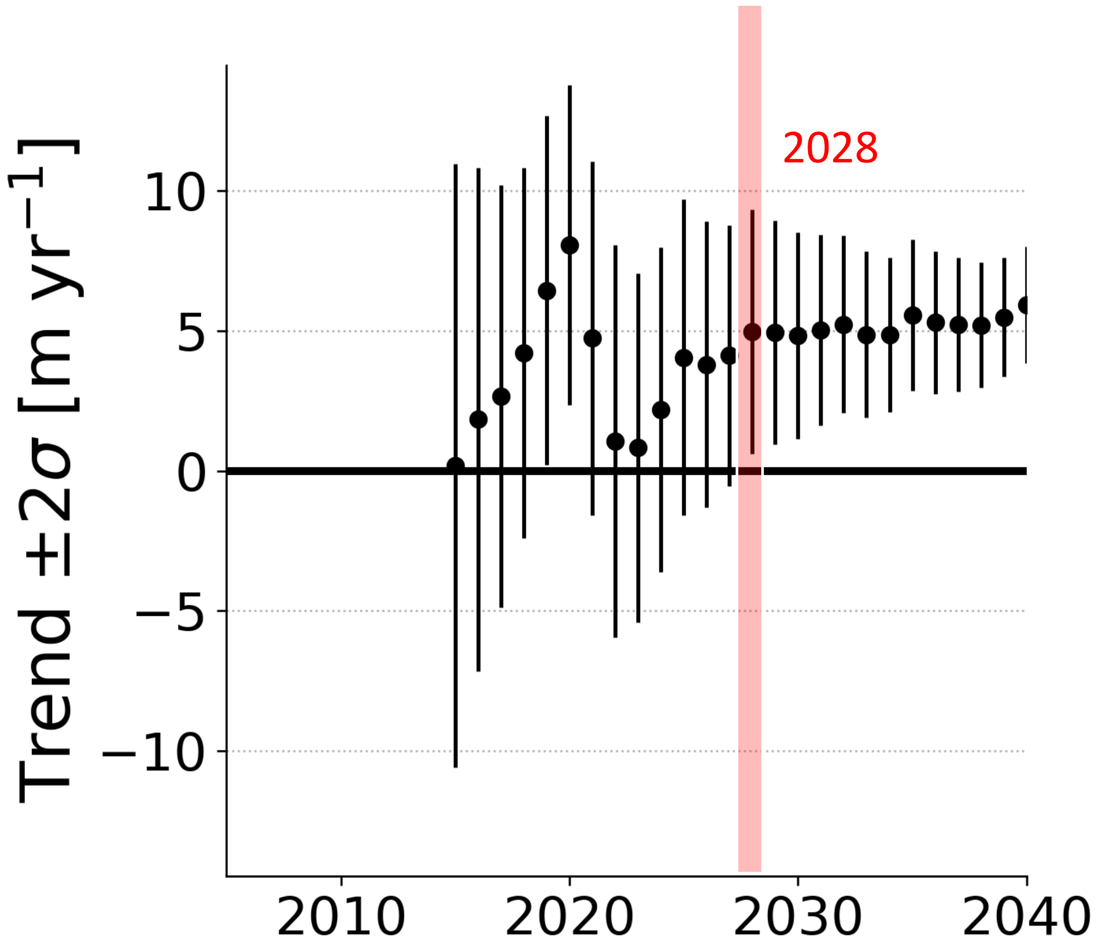




Method: How do we quantify this shift?

- Our detection year is first year that's significant with all years after being significant

Problem: We only have a single model realization…. ☹



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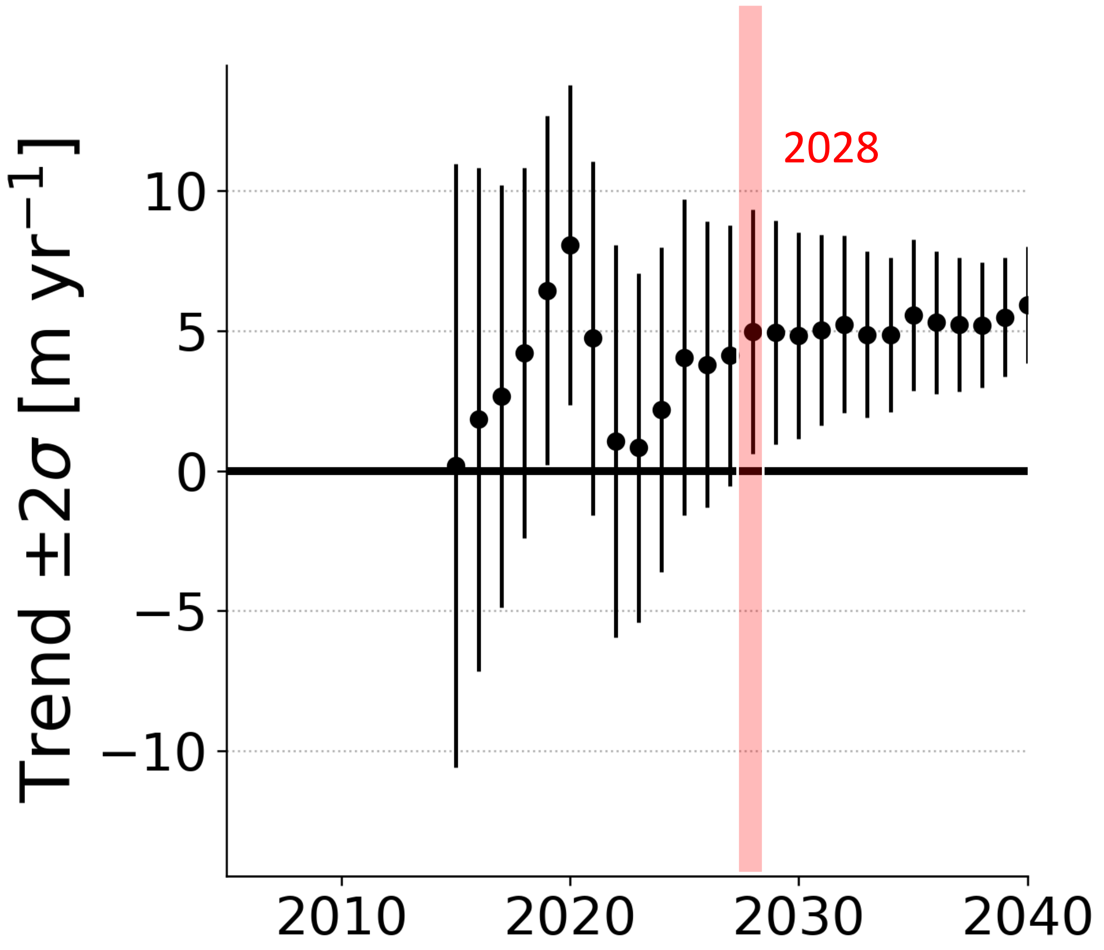
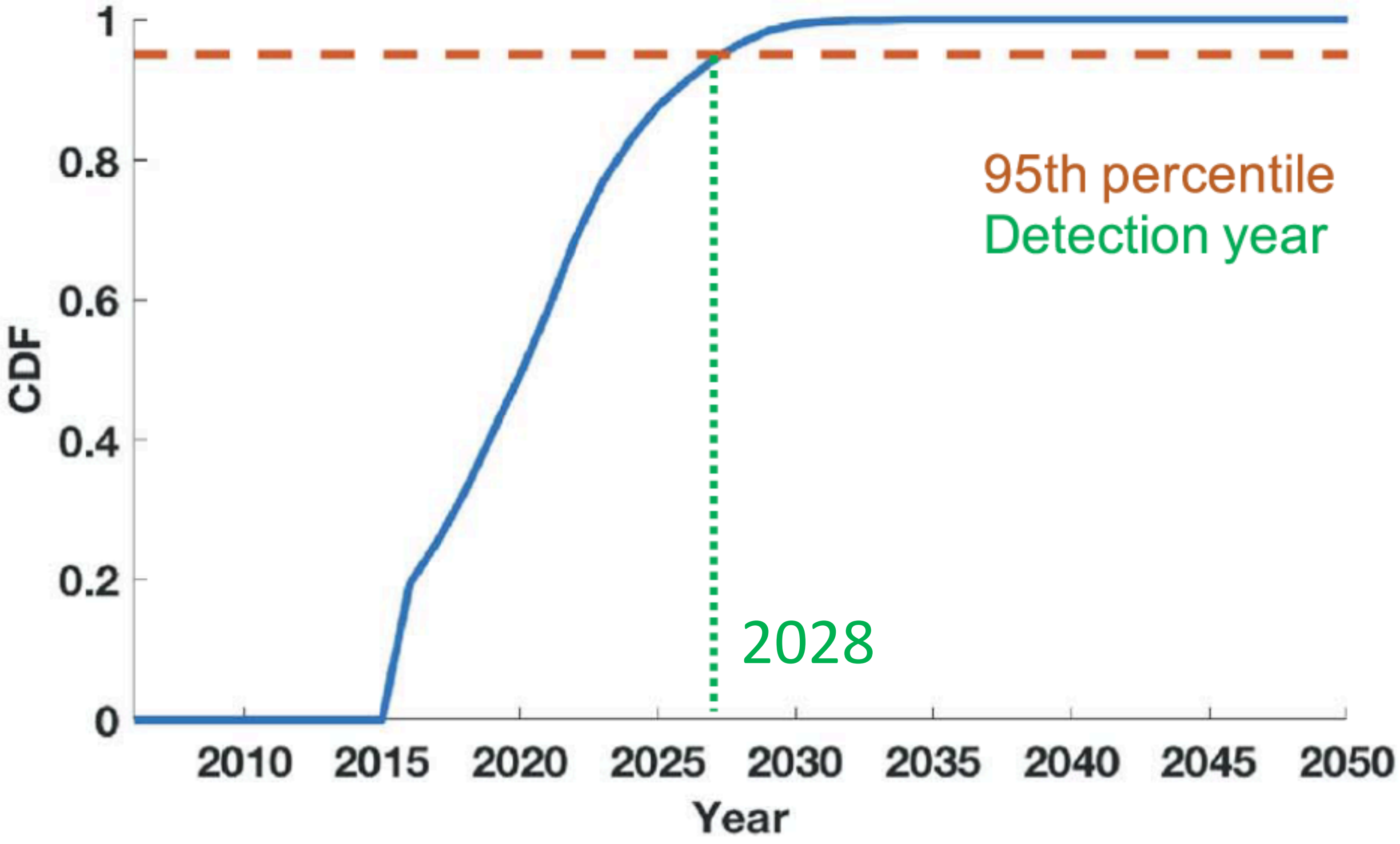


Problem: We only have a single model realization…. ☹

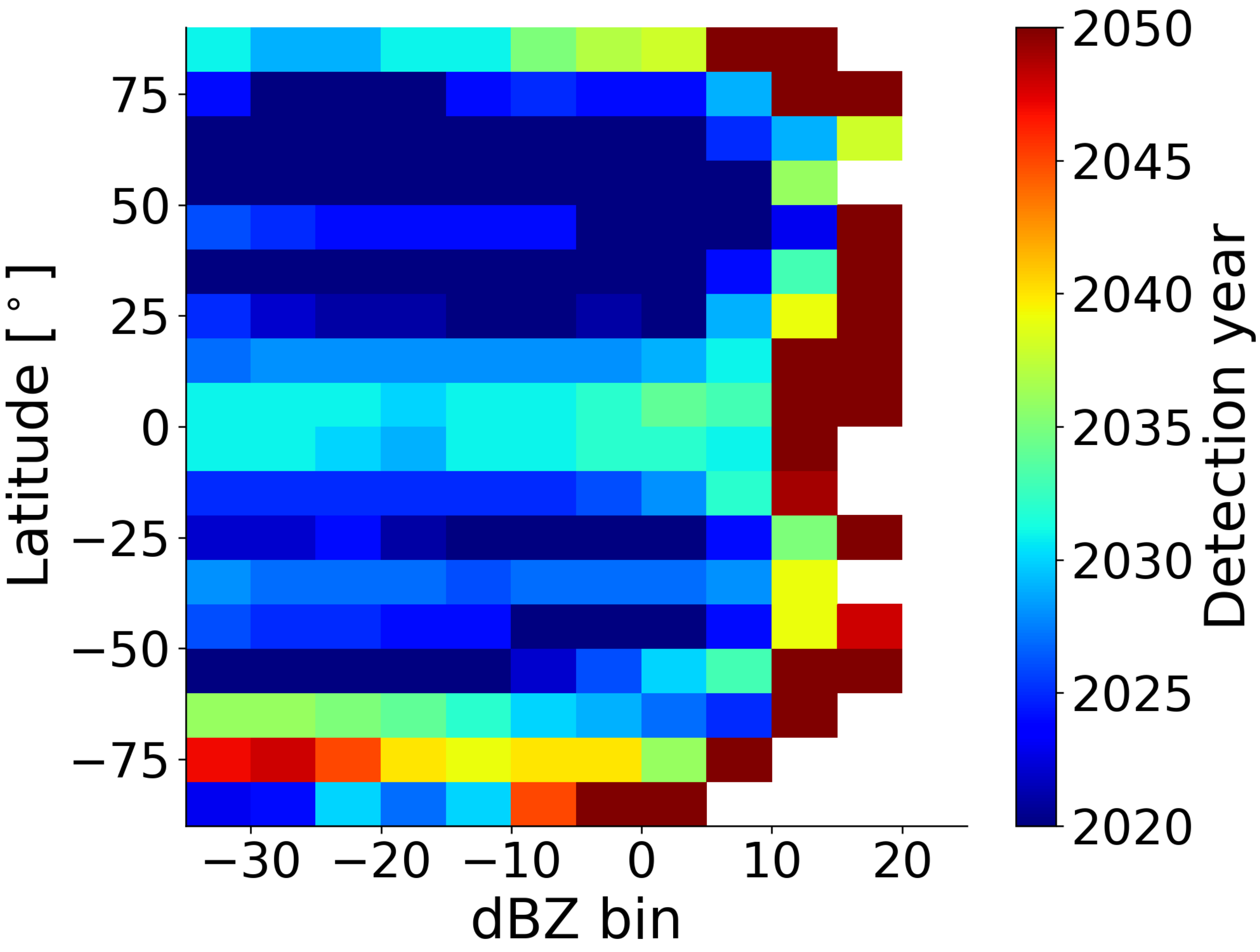
Solution: The WCH trend and variance at each latitude are used to perform **Monte Carlo simulation** of the WCH time series ☺

Method: How do we quantify this shift?

- Cumulative Distribution Function of detection years based on 1000 Monte Carlo simulation

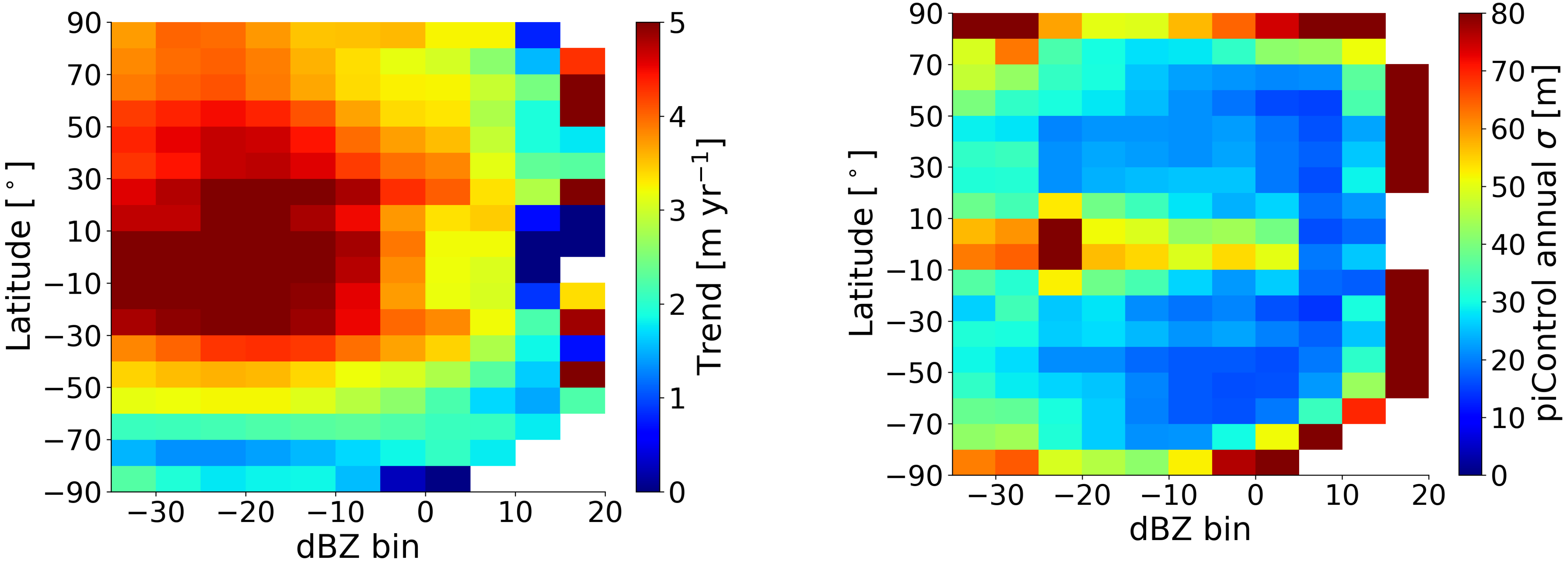


Results: When will we see trends?



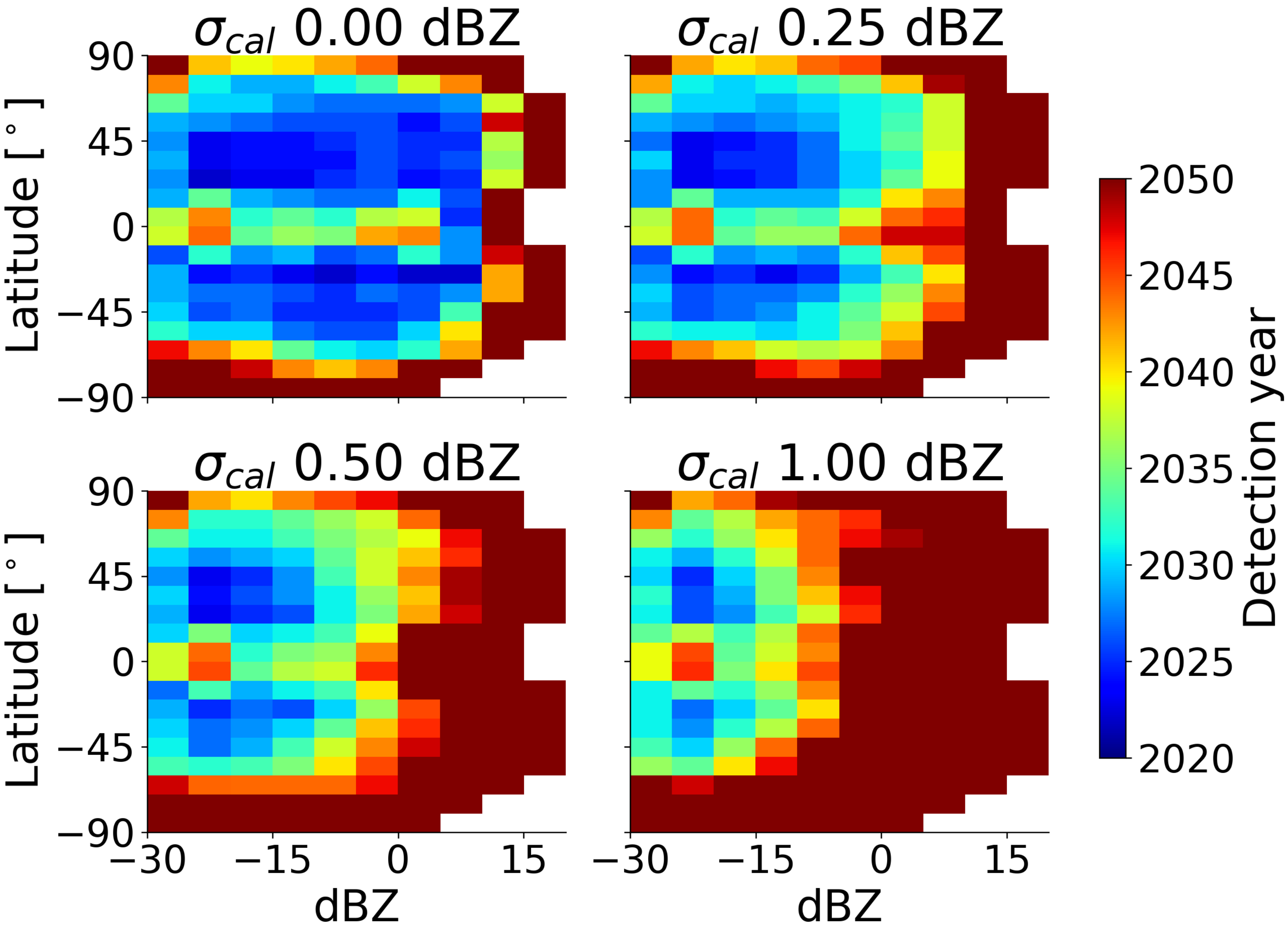
- Detection occurs first in midlatitudes.
- Detection is not largely dependent on the radar sensitivity as long as sensitivity is better approximately 0 dBZ.

Results: When will we see trends?



- The trends are largest in the tropics but so is the variability.
- This masks the detection of the tropical trends relative to the mid-latitude trends.

Calibration error magnitude and detection



- In this worst-case-warming scenario statistically significant trends may be detected as early as the mid 2020’s.
- This CESM simulation suggests that despite the largest trends existing in the tropics, detection will occur first in the mid-latitudes because the natural viability in the tropics is large and will mask detection.
- The results are relatively insensitive to expected uncertainty in radar calibration.
- Detection is possible with both degraded vertical resolution and sensitivity compared to CloudSat meaning low cost radar solutions could reliably monitor the upward shifts.

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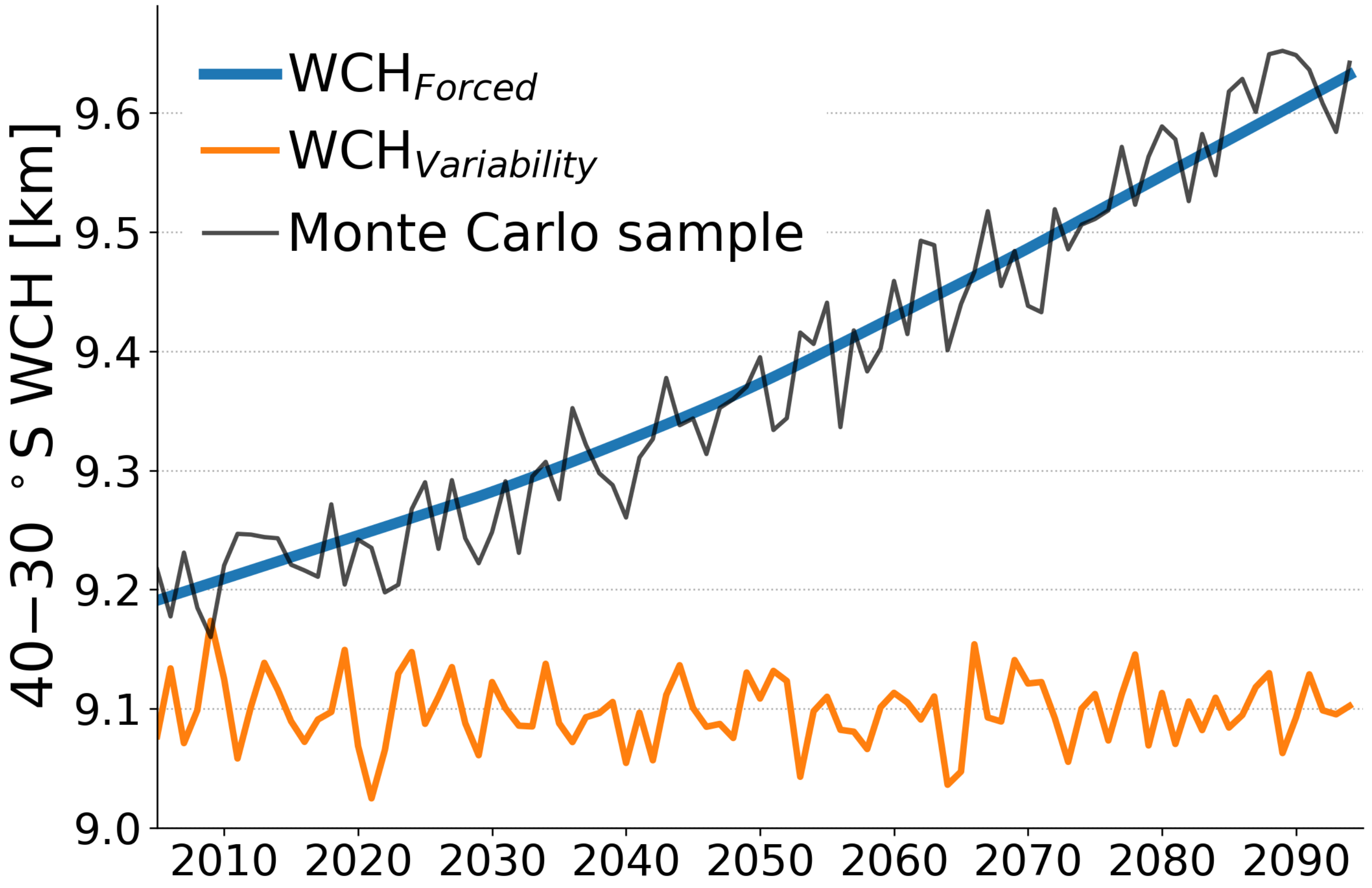
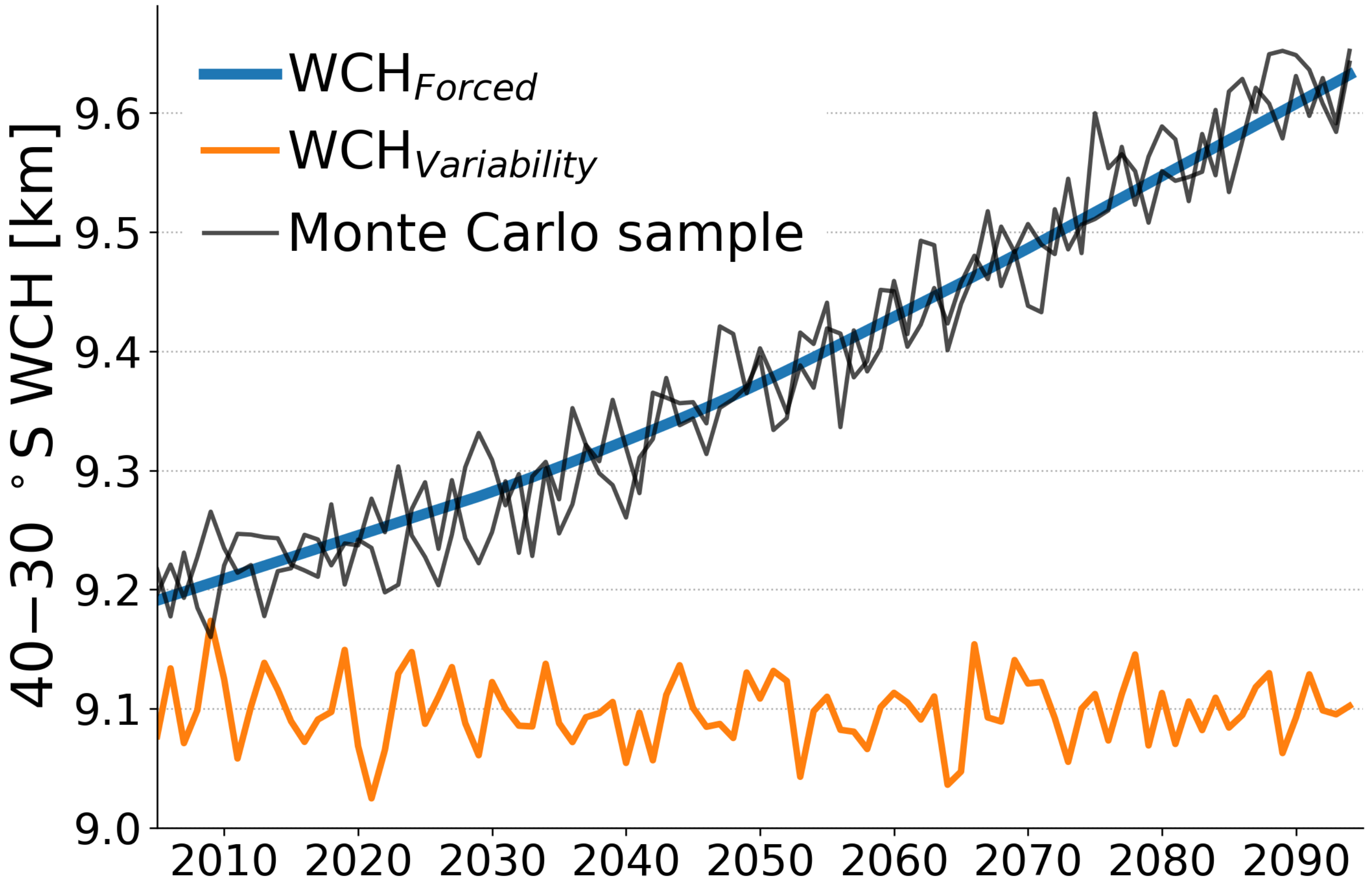
Method: How do we quantify this shift?

Randomly generate WCH_{var}, add to WCH_F



Repeat…



WCH$_{Forced}$
WCH$_{Variability}$
Monte Carlo sample
40−30 °S WCH [km]
9.0
9.1
9.2
9.3
9.4
9.5
9.6
2010
2020
2030
2040
2050
2060
2070
2080
2090

Repeat… and repeat and repeat and repeat…